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A very forward calorimeter for the LHC: experimental results.

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Abstract

We report on measurements performed on a liquid scintillator calorimeter prototype designed for the very forward region in an experiment at the LHC. The liquid scintillator technique has the well known advantages of high speed, low noise and radiation hardness. The proposed solution is a SPACAL-like calorimeter with liquid scintillator circulating in quartz tubes positioned in a lead matrix. The beam tests were performed at the CERN SPS with electrons and pions in the range 20-120 GeV. Results on the energy response and resolution are presented.

1. Introduction

The technique of liquid scintillator well matches all the requirements for the very forward calorimetry at an LHC experiments i.e. lateral granularity in the range $\Delta\eta$ x $\Delta\phi$ $\leq$ 0.2 x 0.2, energy resolution better than $100\%/\sqrt{E} \oplus 10\%$, high speed ($\leq$ 25ns), radiation hardness and low noise[1]. The proposed solution is a calorimeter with liquid scintillator circulating in hollow light guides embedded in a lead matrix.

In this paper we report on the design, the construction and the tests on electron and pion beams of a four-module prototype calorimeter. The results are compared with the Monte Carlo predictions and estrapolated to a fully containing calorimeter.

2. The calorimeter design

The calorimeter has modular structure[2,3,4]. Each module has parallelepiped shape with 66 x 66 mm^2 cross section and 2380 mm length, including a 380 mm long photodetector housing (see Fig.1).

It consists of a lead matrix (the absorber) containing 81 quartz tubes with inner diameter of 3 mm and wall thickness of 250 μm. The tubes run parallel to each other along the module to form a square transverse pattern and the modules are aligned parallel to the beam line. The spacing between tubes (center-to-center) is 7.3 mm, providing a 6:1 ratio between lead and scintillator[2,3].

The modules were constructed by stacking grooved lead plates produced by casting. Then, 2010 mm long stainless steel tubes with inner diameter of 3.8 mm and wall thickness of 200 μm were placed into the grooves.

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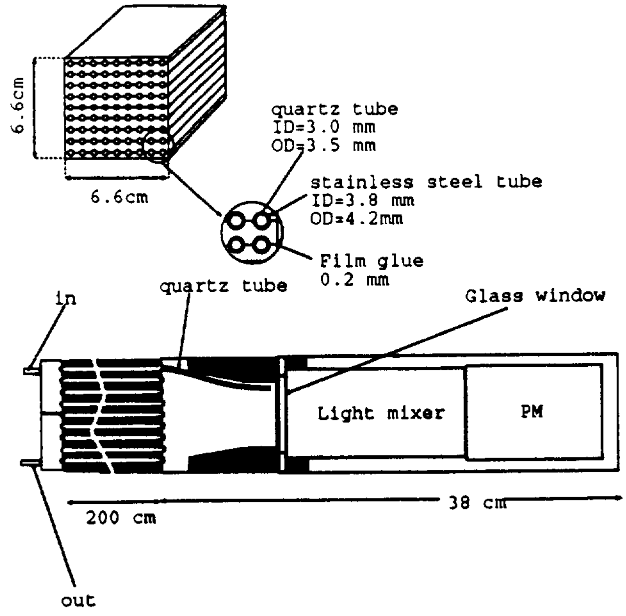

Fig.1 Calorimeter module design.

The lead plates were glued together by means of a special 100 μm thick tape placed under and above the tubes and by compression at high temperature. The compression was released after glue hardening. The tubes coming out at both ends of the module were inserted into holes drilled in stainless steel manifolds and then tin soldered.

The front manifold has inlet and outlet pipes separated by a membrane. The back one is provided with a frame with a glass window, to transmit the scintillation light. The module is followed by a 15 cm long plexiglass light mixer and a photomultiplier.

The modules were washed with a purified alcohol flow circulated by a pump during a few hours and then dried with air. The quartz tubes were inserted from the back of the modules. The last 10 cm of the tubes' far end were bent to form a bundle of 42 x 42 mm^2 cross-section.

The modules were blown with argon, then filled under argon atmosphere. Finally the liquid was circulated by a pump to remove bubbles. The outlet pipe was then connected to a buffer volume filled up to 1/3 with scintillator and 2/3 with argon.

3. The beam tests

A prototype calorimeter made of 2 x 2 (full scale) modules was tested with pion and electron beams at the CERN SPS in July 1994. The calorimeter was placed parallel to the beam direction on a movable table allowing displacement in the vertical and horizontal directions and tilt in the horizontal plane.

For three of the four modules BC599-13G BICRON scintillator (green emitting) was used; the fourth was filled with methylnaphtalene. The modules were equipped with filters to enhance the attenuation length of the light, and read by EMI 9839A photomultipliers.

A sketch of the experimental set-up is shown in Fig. 2. A veto counter limited the lateral dimensions of the beam, and two scintillation counters (S_2 and S_3) were placed before a variable amount of material used as a preradiator, to define a beam spot size of 7 x 7 mm^2. Another 7 x 7 mm^2 scintillation counter (S_5) preceded a $2X_o$ lead preshower and a scintillation counter placed in front of the modules.

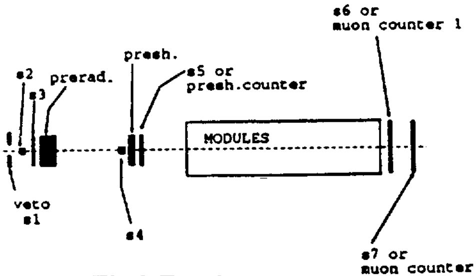

Fig.2 Test beam set-up.

The modules were followed by two scintillator plates used to detect passing through muons. All counters were read-out to allow an off-line event selection, while the trigger was given by the coincidence of S_2 and S_3 only.

4. Experimental results

The calorimeter was exposed to electron and pion beams of 20, 40, 80, 120 GeV; the modules were calibrated by hitting 120 GeV pions on their center and equalizing the response.

Fig. 3(a) shows the energy distributions for 120 GeV electrons with 1° tilt angle with and without a $3X_o$ preradiator. In the data without preradiator a high energy tail is clearly visible, due to channelling effects. The use of preradiator strongly reduces this effect and the RMS of the distributions is decreased by 50%.

Fig. 3(b) shows distributions with the $3X_o$ preradiator for 1° and 3° tilt angles. As expected, the increase of the tilt angle results in a better energy resolution. Response and resolutions have been studied for 120 GeV electrons also as a function of the preradiator thickness.

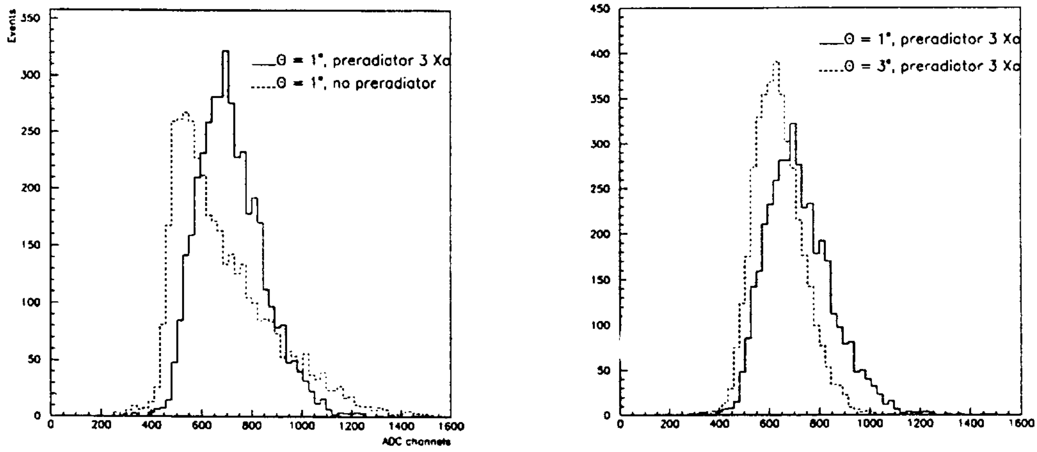

Fig.3 (a) Energy distribution for 120 GeV electrons with and without preradiator; (b) energy distribution with preradiator at two different angles.

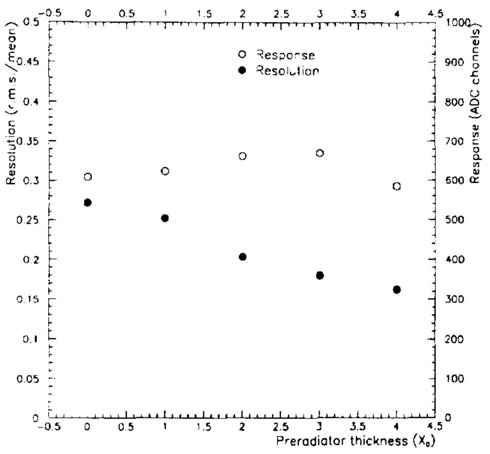

Fig.4 Energy response and resolution for 120 GeV electrons vs preradiator thickness.

Fig. 4 shows that while the response is almost constant for the whole range explored, the resolution improves by the thickness. The calorimeter was also tested with pions for two different values of the tilt angle (0° and 1°).

Fig. 5 shows the response distribution for 120 GeV pions. The low energy tail is due to lateral leakage and well explained by a Monte Carlo simulation. Energy respose and resolution are shown in Fig. 6. Unlike for the electon events the resolution for pions is obtained from a gaussian fit of the distributions in a $\pm 2\sigma$ region around the peak.

The result is $\sigma/E = 86\%/\sqrt{E(\mathrm{GeV})}+7\%$ corresponding to a $51\%/\sqrt{E(\mathrm{GeV})}+8\%$ resolution for the full calorimeter, well below the limits imposed by the LHC design of the ATLAS experiment[1].

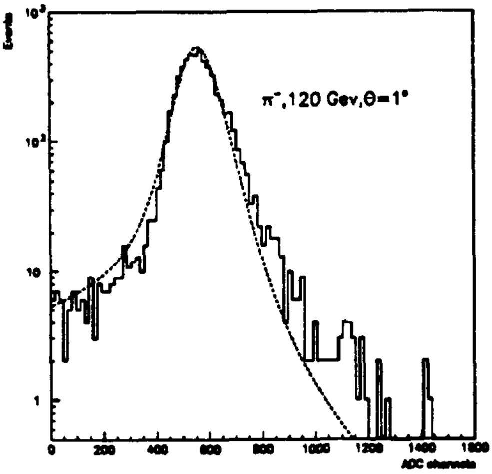

Fig.5 Energy distribution for 120 GeV pions at 1°. The dashed line is the result of a Monte Carlo simulation.

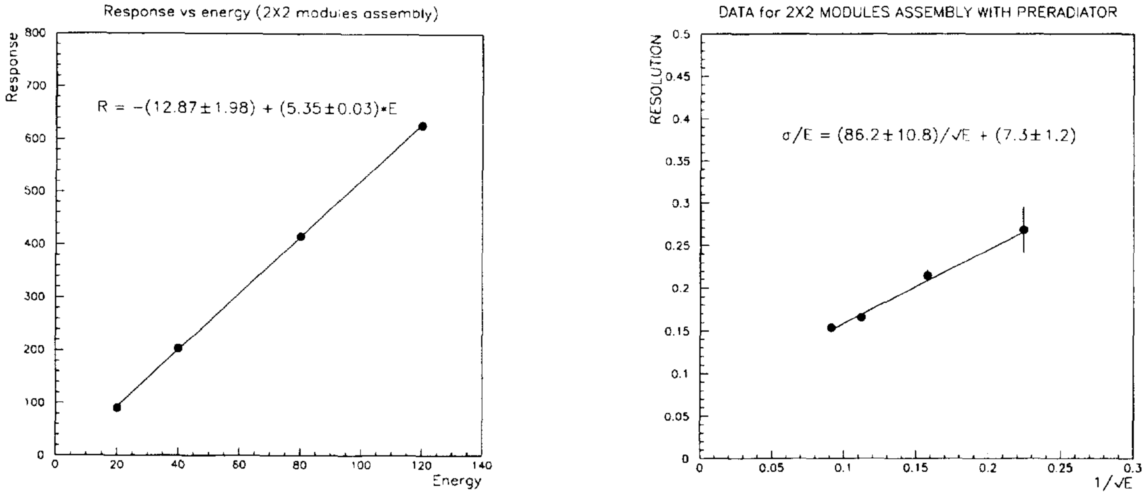

Fig.6 Pion energy response and resolution as a function of 1/√E(GeV).

5. Conclusions

We have designed constructed and tested a prototype lead-liquid scintillator calorimeter to be possibly used as a forward calorimeter in a LHC detector. Good energy resolution for electrons is obtained even at small incidence angles by using a passive preradiator in front of the modules. The response to pions is linear and the energy resolution is σ/E = 86%/√E(GeV)+7% corresponding to 51%/√E(GeV)+8% for the full calorimeter.

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